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TEST AND EVALUATION OF SOLID STATE POWER CONTROLLERS

VEHICLE POWER BRANCH
AEROSPACE POWER DIVISION

DECEMBER 1976

TECHNICAL REPORT AFAPL-TR-76-95
FINAL REPORT FOR PERIOD JULY 1974 THROUGH JUNE 1976

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This report covers the in-house test and evaluation of solid state power controllers developed by Westinghouse under contracts F33615-71-C-1400 and F33615-73-C-2082. Among these power controllers were units intended for use on the B-1.

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FOREWORD

This report contains the results of the testing of solid state power controllers as developed by the Westinghouse Corporation for AFAPL. The work was performed by the Aerospace Power Division, Vehicle Power Branch of the Air Force Aero Propulsion Laboratory, Wright-Patterson AFB, Ohio, under Project 3145, Task 314529, and Work Unit 31452929. This effort was conducted by Mr. Joseph M. Farkas, AFAPL POP-2, during the period July 1974 through June 1976.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

I. Introduction

This report covers the in-house test and evaluation of solid state power controllers developed by the Westinghouse Corporation for AFAPL under Contracts F33615-71-C-1400 and F33615-73-C-2082. Among these power controllers were units intended for use on the B-1.

A total of 45 power controllers were tested from July 1974 through June 1976.

II. Evaluation Procedures and Results

A total of 45 power controllers were subjected to various electrical tests. The power controllers were the end products of two contracts. Delivered under the first contract were:

1. 1-230 volt, 1.0 ampere rated power controller
2. 5-230 volt, 2.0 ampere rated power controllers
3. 6-230 volt, 5.0 ampere rated power controllers

The second contract was coordinated with the B-1 System Program Office. The power controllers were designed to meet the needs of the B-1 electrical system. Delivered and tested were:

1. 1-230 volt, 1.5 ampere rated breadboard power controller
2. 7-230 volt, 1.5 ampere rated B-1 prototype power controllers
3. 25-230 volt, 1.5 ampere rated B-1 prototype power controllers

with Integrated Wire Terminal System (IWTS) connectors. Figure 1 shows examples of the power controllers tested. Detailed electrical specification testing was performed on all but the IWTS power controllers. The IWTS power controllers were configured on a test bench and operated with the in-house Electrical Multiple System (EMUX). The electrical characteristics tested were:

1. Turn on and turn off control voltage and current

2. Turn on and turn off delay

3. Power pass element voltage drop

4. Power dissipation

5. Overload time trip characteristics

6. Zero turn on and turn off accuracy

7. Trip and status indicator voltage drop

8. Power pass element leakage current

All specification tests were performed at room temperature.

The numerical results of the specification tests are listed in Tables 1-4.

An explanation of the necessity for making the measurements, the method by which they were accomplished, and some of the results obtained are as follows:

1. Turn on and turn off voltage and current. The turn on voltage is the minimum voltage that applied to the control inputs, allows the power controller to pass load current. In a similar manner the turn off voltage is the control voltage that results in the "on" power controller in turn "off". These voltages, and the resulting currents, are in the 5 volt and 10 milliampere range, making these power controllers compatible with solid state logic. Oscillatory operation of the power controller is prevented by the hysteresis designed into the control input circuit.

2. Turn on and turn off delay. The delay to turn on is the time from application of a 5 volt control signal to the actual application of the current to the load. The turn off delay is the time from removal of the 5 volt control signal to the time the load current goes to zero. The delays experienced with these power controllers were by

design to meet the B-1 specifications. Figures 2 and 3 show the typical turn on and turn off delay.

3. Pass element voltage drop. The voltage drop was measured between the power controllers 230 volt input and 230 volt output leads with various loads applied. This voltage was measured with a Fluke 8300A true RMS reading digital voltmeter and with an oscilloscope. Figure 4 and Figure 5 show pictures of the typical voltage drops observed.

This measurement is made to determine if the voltage drop due to a solid state power controller would be great enough to have an undesirable effect on aircraft loads. No problems were observed due to a voltage drop, the typical drop being about 1.7 volts RMS with a 1.5 ampere load.

4. Power dissipation. Power dissipation is one of the most critical and one of the most difficult to measure parameters. It is composed of the sum of all the individual circuit losses within the power controller. This includes the pass element, ground circuit, control input, and status and trip indicator losses. The pass element and ground circuit losses form the majority of the power loss in these power controllers.

Two methods were used to obtain the sum of the losses in the pass element. One method was to obtain the two losses individually and sum the results. The power switch loss was computed by measuring the RMS voltage drop and multiplying by the RMS current. This gives the average power dissipation in the pass element.

The ground circuit loss was more difficult to measure. Westinghouse uses a capacitor voltage divider to supply power for the internal circuitry. This results in a ground current of large magnitude but small power factor. A Philips multiplying oscilloscope was used to take the

product of the line voltage and ground current and give a DC output signal directly proportional to the real power loss. This output was applied to a digital voltmeter which, in combination with the proper oscilloscope input and current probe settings, would display power dissipation directly in milliwatts. This number was added to the number calculated for the power switch loss to give the total power dissipation.

A second method was to use an instrument built in-house specifically to measure the losses in these two sections. This was comprised of 2 analog multipliers and a summing amplifier. This instrument outputted a DC voltage proportional to the power dissipation. This instrument was used to measure the power dissipation of the power controllers under life test after 2300 hours of operation. The two methods gave very nearly the same results; that the power controller was under the 4 watt full-load dissipation limit and over the 0.5 watt off state dissipation limit specified by the B-1.

5. Overload time trip characteristics. Overload time trip characteristics were determined to verify the power controllers to protect aircraft wiring and open a fault. Up to 500 amperes were passed by the 5 ampere rated prototypes for ½ cycle under fault conditions. The B-1 prototypes contained an internal resistor to limit fault currents. Up to 260 amperes were conducted by these units under fault conditions. Typical trip characteristics are plotted in Figures 6 and 7.

6. Zero turn on and turn off accuracy. One of the reasons for utilizing solid state power controllers is the advantage of zero voltage turn on and zero current turn off. Zero voltage turn on results in a "softer" turn on for inductive and lamp loads, thus reducing EMI and increasing lamp filament life. Contact bounce associated with relay control of load current is

eliminated, making the life of power controllers many thousands of hours. Zero current turn off reduces the voltage spike created when the current through an inductive load is suddenly brought to zero. These power controllers utilize Silicon Controlled Rectifiers (SCR's) as the power pass element which theoretically turn off on zero current. These devices turn off within 10 microseconds after the zero current crossover point. Figures 8 and 9 show the turn on and turn off voltage and currents with a resistive load, and Figures 10, 11, and 12 show turn on and turn off with a transformer-rectifier as a load.

7. Trip and status indicator voltage drop. The trip and status indicators are transistor switches that close when the power controller has tripped or when gate drive is supplied to the SCR's. The drop across these switches is minimal up to the 10 milliampere rating.

8. Power pass element leakage current. Leakage current of the pass element was measured by a digital milliamp meter between the 230 volt output and neutral with the power controller control at zero. This measurement was made to check for potential shock hazard to personnel working on loads connected to turned off power controllers. These currents were less than 100 microamperes.

These power controllers were operated with various loads including three phase motor, relays, various inductors, lamps, capacitors, and transformer-rectifiers. No problems were observed in the operation of any of these loads. A life test fixture was set up consisting of six B-1 prototypes, 4 loads and a timing circuit. Figure 13 shows the life test configuration. These controllers were subjected to a 50% duty cycle, 100 cycles per hour, for about 9 hours per working day. The loads included a B-1 transformer-rectifier, 150 ohm resistor, two 120 volt, 150 w lamps,

and a 200 volt 3 phase aircraft fan. These power controllers were connected line-to-line across the 400 Hertz source and the voltage upped to 230 volts line-to-line. Three 30 ohm resistors were added in line to the 3 phase fan to drop the voltage to 200 volts line-to-line. The power controllers were subjected to specification test and then placed under life test. At 500 hours the six power controllers were again tested, and then placed back into life test operation.

At 800.3 hours of operation, Westinghouse unit #21 failed. The failure has been attributed to the failure of one of the capacitors in the input power supply voltage divider. This capacitor according to Westinghouse failure analysis, was damaged upon installation on the hybrid chip. This turned out to be a potential problem in all of the B-1 power controllers.

The failed power controller was replaced with unit #20. After an additional 1150.1 hours, this replacement power controller failed, the cause being the same as in the previous failure. This unit was not replaced. The failure was not attributed to any peculiarities in the test configuration or to the load, which may have increased the stress on the power controller.

At 2000 hours the 5 remaining power controllers were again tested. During this testing, 40 volts DC was inadvertently applied to the control terminals of controller #25. This caused a zener diode in the input circuitry to fail short, making the power controller inoperative. Five volts at several amperes was then applied to the control terminals in an attempt to "burn out" the shorted zener diode. This was successful, and the power controller was again operative. But further testing revealed that the power controller would no longer trip on overloads.

The reason for this has not been determined.

Comparison of the data revealed little change in characteristics over the 2000 hours. Any differences can be attributed to improved test procedures that result in more accurate data or changes in the test equipment during the passing of one year. A rise in the off state power dissipation has been detected. This has been attributed to leakage of the power supply voltage divider capacitors. This increase may be a prelude to the eventual failure of one of these capacitors.

Eighteen of the solid state power controllers with IWTS connectors were installed on a test bench to be controlled by the Laboratory EMUX system, see Figure 14. A test box delivered with the EMUX system was modified to provide an interface between the power controllers and the remote terminals of the EMUX system. These test boxes provide a means of entering and displaying "ones" and "zeros" into and from the remote terminals, and also provide external jacks for entering and receiving data from other sources.

Figure 15 shows the modification and method of connecting the power controllers control, trip, and status. With this configuration, the trip and status can be taken from the power controller or forced to one or zero from the switches. This allowed simulated trips to be made without actually placing a fault on a power controller.

Originally 24 of the IWTS power controllers were to be connected to the EMUX system. Six failed before it was realized that a problem existed with the voltage divider capacitors. Once the reason for the failures was discovered, a current limit circuit was built and inserted into the neutral return lead of each of the remaining power controllers. This circuit, Figure 16, would limit the current to the power controller

to 100 ma. This would prevent excessive currents from flowing through the capacitors during turn on and hopefully prevent additional failures. None of these protected power controllers has failed because of a power supply capacitor failure.

A variety of loads, listed in Figure 17, were connected to the 18 power controllers. A program was written in the Powertran language to configure the EMUX system. This program provided automatic cycling or manual control of the loads, reset of tripped power controllers, and 3 phase load control. The Appendix contains a listing of this program.

During the automatic cycling mode, the 3 phase load, in this case a motor, would operate in one phase sequence for 30 seconds, then off for 2 seconds, then run in a different phase sequence for 30 seconds. This would reverse the 3 phase motor. A trip input from any one of these power controllers would turn all of the power controllers off.

Power controllers that trip are reset a maximum of three times. On the receipt of the third trip signal the control is turned off and a message sent to the EMUX's Crew Control and Display Panel to notify that the power controller has tripped. Reset of the power controller is accomplished by moving the control input switch to "zero" and back to "one."

The 18 power controllers have been manually and automatically cycled for over 350 hours.

At 340 hours a failure within the EMUX system forced all outputs to "one." This resulted in the power controllers in the three phase circuit to be turned on line-to-line. These power controllers tripped immediately and continued to operate properly after the EMUX system was restored to normal operation. But a checkout of the remaining power con-

trollers revealed that two others had failed in the on state. The power pass section in power controller no. 8 had failed. This was verified when removal of the neutral return from the power controller had no effect on its operation. Power controller number 11 had a failure within the control circuitry. Removal of its neutral return would turn the power controller off. No attempt has been made to analyze the power controller internal workings to find out why they failed. The hermetic construction of the controllers makes any attempt to open the container extremely difficult.

It was not possible to determine if the failure of these two power controllers was related in any way to the failure of the EMUX system. The shorting of the two phases by the three phase load power controllers may have created a disturbance on the line of sufficient amplitude to affect the controllers.

III. Conclusions

These power controllers developed by Westinghouse are capable of performing to the specifications to which they were designed. They are not recommended for flight test because of the manufacturing problem that may result in the failure of the power supply capacitor. Also, the effect of line transients on the power controller should be fully investigated before such units are flight tested.

The operation of these power controllers with various loads and with an EMUX system has been successful. No compatibility problems have arisen in the 18,800 hours accumulated by the power controllers to date. Life testing will continue with the intent of uncovering any long term degradation that may occur in solid state power controllers.

IV. Recommendations

In the light of the failure of two power controllers controlled by the EMUX system, it is highly recommended that the effects of power line transients on power controllers be investigated. Transients similar to the ones that occurred during the temporary failure of the EMUX system may happen during normal or emergency bus switching procedures or the application and removal of large loads from the electrical bus. The effect of these transients on solid state power controllers will have to be investigated and documented.

Upon completion of the High Speed Data Acquisition System in the Power Generation and Distribution Laboratory at AFAPL,transient tests will be performed on a simulated aircraft bus with solid state power controllers. The information obtained from this testing will be made available to the manufacturers of solid state power controllers.

Table 1. Electrical Characteristics of Westinghouse Solid State Power Controllers

Unit Number	6	1	2	3	4	5	6
Rating	1 A	2 A	2 A	2 A	2 A	2 A	2 A
Control							
V on	2.21 V	2.29 V	2.28 V	2.30 V	2.29 V	NOT TESTED	DEFECTIVE
V off	2.16 V	2.22 V	2.21 V	2.22 V	2.22 V		
Turn on delay	7.7 msec	7.5 msec	7.0 msec	8.9 msec	6.0 msec		
Turn off delay	6.6 msec	7.0 msec	7.0 msec	6.7 msec	7.2 msec		
Pass Section							
V drop							
@ rated load	8.0 V_{p-p}	1.92 V_{rms}	1.88 V_{rms}	1.88 V_{rms}	1.86 V_{rms}		
		8.7 V_{p-p}	6.8 V_{p-p}	4.8 V_{p-p}	6.8 V_{p-p}		
@ no load	4.0 V_{p-p}	1.67 V_{rms}	1.25 V_{rms}	1.67 V_{rms}	1.64 V_{rms}		
		5.6 V_{p-p}	4.2 V_{p-p}	4.6 V_{p-p}	4.2 V_{p-p}		
Overcurrent Protection							
Minimum pickup	1.4 A_{rms}	3.1 A_{rms}	3.0 A_{rms}	2.8 A_{rms}	2.9 A_{rms}		
½ cycle trip	20.8 A_{peak}	43 A_{peak}	40 A_{peak}	43 A_{peak}	46 A_{peak}		

Table 2. Electrical Characteristics of Westinghouse Solid State Power Controllers

Unit Number	1	2	3	4	5	6
Rating	5 A	5 A	5 A	5 A	5 A	5 A
Control						
V on	2.29 V	2.33 V	2.30 V	2.30 V	2.33 V	2.31
V off	2.23 V	2.26 V	2.23 V	2.23 V	2.25 V	2.23
Turn on delay	8.4 msec	8.4 msec	6.3 msec	6.8 msec	7.2 msec	8.5 msec
Turn off delay	6.7 msec	5.9 msec	7.2 msec	7.6 msec	7.0 msec	6.5 msec
Pass Section						
V drop						
@ rated load	1.44 V_{rms}	1.44 V_{rms}	1.52 V_{rms}	1.45 V_{rms}	1.44 V_{rms}	3.62 V_{rms}
	8.2 V_{p-p}	9.6 V_{p-p}	8.0 V_{p-p}	9.2 V_{p-p}	8.1 V_{p-p}	42 V_{p-p}
@ no load	1.61 V_{rms}	1.67 V_{rms}	1.66 V_{rms}	1.65 V_{rms}	1.68 V_{rms}	17.76 V_{rms}
	4.0 V_{p-p}	4.4 V_{p-p}	4.1 V_{p-p}	4.4 V_{p-p}	4.5 V_{p-p}	58 V_{p-p}
Overcurrent Protection						
Minimum pickup	7.5 A_{rms}	7.5 A_{rms}	7.3 A_{rms}	7.3 A_{rms}	7.1 A_{rms}	7.5 A_{rms}
1/2 cycle trip	111 A_{peak}	102 A_{peak}	107 A_{peak}	100 A_{peak}	110 A_{peak}	100 A_{peak}

Table 3. B-1 Power Controller Data Prior to Life Test Electrical Characteristics

Life Test Unit Number/ Westinghouse No.	1/11	2/21	3/23	4/24	5/25	6/39
Control						
I @ 5 V	6.59 mA	6.50 mA	6.46 mA	6.37 mA	6.79 mA	6.84 mA
Turn on V&I	3.13 V, 2.10 mA	3.13 V, 2.09 mA	2.86 V, 1.40 mA	2.93 V, 1.56 mA	2.91 V, 1.62 mA, 2.94 V	1.66 mA
Turn off V&I	3.01 V, 1.80 mA	3.03 V, 1.87 mA	2.78 V, 1.23 mA	2.84 V, 1.39 mA	2.84 V, 1.49 mA, 2.87 V	1.59 mA
Turn on delay	12.0 msec	12.4 msec	7.5 msec	6.0 msec	7.0 msec	12.0 msec
Turn off delay	12.0 msec	12.5 msec	12.5 msec	12.0 msec	12.0 msec	12.0 msec
Pass Section						
V drop @ rated load	1.614 V_{rms}	1.600 V_{rms}	1.597 V_{rms}	1.629 V_{rms}	1.614 V_{rms}	1.610 V_{rms}
	4.1 V_{p-p}	4.05 V_{p-p}	4.0 V_{p-p}	4.1 V_{p-p}	4.1 V_{p-p}	4.0 V_{p-p}
Leakage	0.09 mA	0.08 mA	0.09 mA	0.14 mA	0.15 mA	0.07 mA
Overcurrent Protection						
min I & T	2.2 A-10 sec	2.2 A-7 sec	2.2 A-5 sec	2.1 A-9 sec	2.2 A-9 sec	2.2 A-5 sec
3.0 A_{rms}	1.2 sec	0.9 sec	1.1 sec	0.8 sec	0.9 sec	1.2 sec
10.0 A_{peak}	120 msec	92 msec	100 msec	100 msec	130 msec	122 msec
1/2 cycle	40 A_{peak}	40 A_{peak}	38 A_{peak}	35 A_{peak}	40 A_{peak}	50 A_{peak}
Trip Circuit						
V drop @ 10 mA	60 mV	75 mV	87 mV	82 mV	90 mV	57 mV
Power Dissipation						
Off	0.49 w	0.45 w	0.46 w	0.45 w	0.47 w	0.45 w
On with 1.5 A load	3.82 w	3.75 w	3.78 w	3.82 w	3.81 w	3.79 w
Tripped	1.09 w	1.02 w	1.08 w	1.05 w	1.02 w	1.01 w

Table 4. B-1 Power Controller at 2000 Hours of Life Test Electrical Characteristics

Life Test Unit Number/ Westinghouse No.	1/11	2/21	2/20	3/23	4/24	5/25	6/39
Control							
I & 5 V	6.60 mA	Failed	Failed	6.61 mA	6.56 mA	Failed	6.70 mA
Turn on V&I	3.14 V, 2.09 mA			2.87 V, 1.52 mA	2.94 V, 1.66 mA	Before	2.94 V, 1.66 mA
Turn off V&I	3.02 V, 1.83 mA			2.78 V, 1.32 mA	2.87 V, 1.33 mA	Completion	2.87 V, 1.59 mA
Turn on delay	11.6 msec			7.5 msec	8.4 msec	9.0 msec	8.8 msec
Turn off delay	12.4 msec			12.8 msec	12.0 msec	12.0 msec	12.0 msec
Pass Section							
V drop	1.645 V_{rms}			1.650 V_{rms}	1.660 V_{rms}		1.610 V_{rms}
	4.2 V_{p-p}			4.2 V_{p-p}	4.2 V_{p-p}	4.2 V_{p-p}	4.2 V_{p-p}
Leakage	0.3 mA			0.1 mA	0.1 mA	0.1 mA	0.1 mA
Overcurrent Protection							
min I & T	2.2 A-9 sec			2.2 A-8 sec	2.2 A-8.2 sec	2.5 A-9 sec	2.2 A-8.4 sec
3.0 A_{rms}	1.2 sec			1.0 sec	1.0 sec	2.4 sec	0.9 sec
10.0 A_{peak}	136 msec			108 msec	112 msec	155 msec	120 msec
1/2 cycle	38 A			34 A	38 A		40 A
Trip Circuit							
V drop @ 10 mA	62 mV			85 mV	83 mV		56 mV
Power Dissipation							
Off	0.58 w			0.60 w	0.57 w	0.78 w	0.62
On with 1.5 A load	3.89 w			3.79 w	4.02 w	3.74 w	3.98
Tripped	1.15 w			1.17 w	0.89 w		0.86

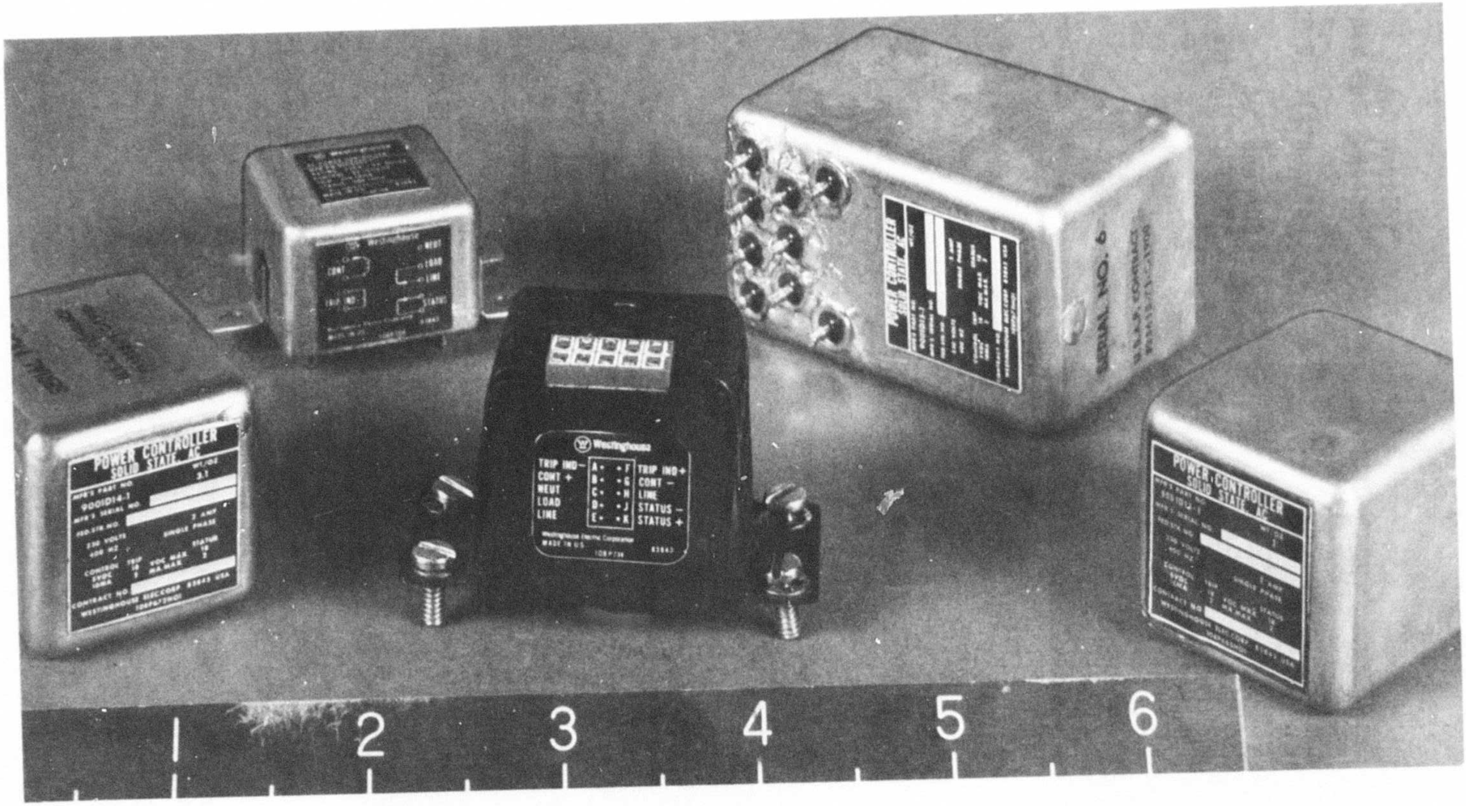
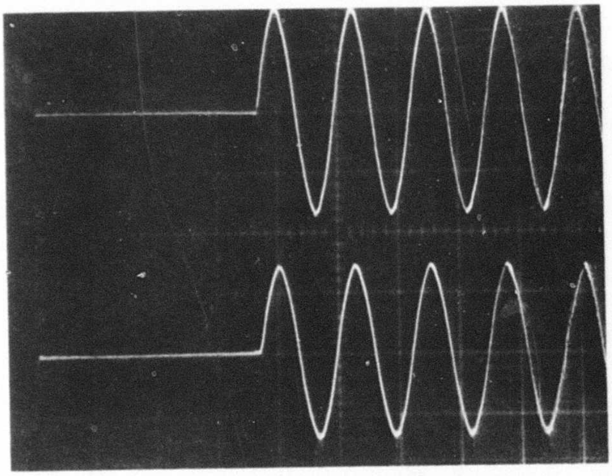


Figure 1 Power Controllers Tested
(Clockwise from Left)

1. 2 Amp, 230 Volt, Power Controller
2. 1.5 Amp, 230 Volt, B-1 Prototype Power Controller
3. 5.0 Amp, 230 Volt, Power Controller
4. 1.0 Amp, 230 Volt Power Controller
5. 1.5 Amp, 230 Volt B-1 Power Controller with IWTS connector



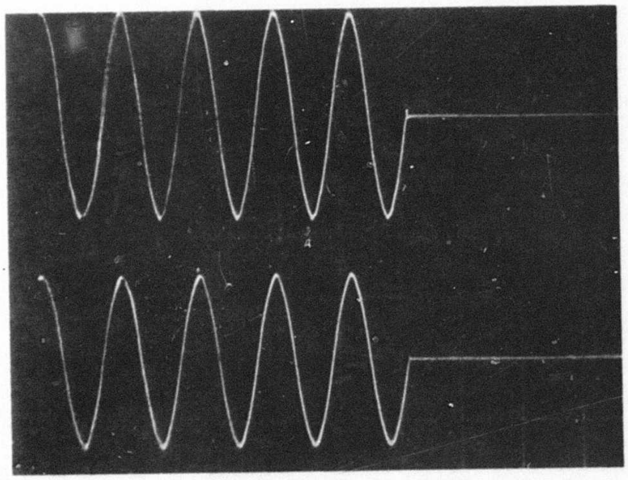
Voltage Out
Scale: 200 V/div

Horizontal: 2 MS/div

Current Out
Scale: 1A/div

↑
Control On

FIGURE 2 Turn On of Westinghouse Power Controller



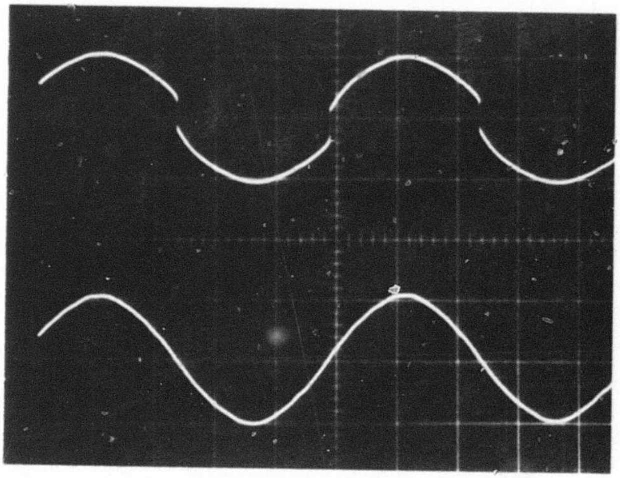
Voltage Out
Scale: 200 V/div

Horizontal: 2MS/div

Current Out
Scale: 1A/div

↑
Control On

FIGURE 3 Turn Off of Westinghouse Power Controller

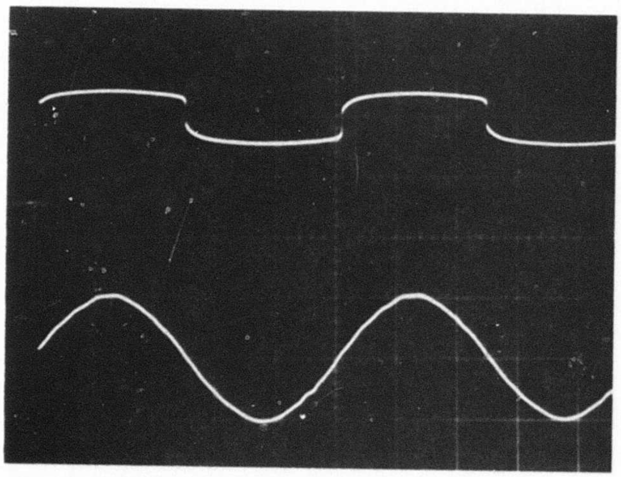


Voltage Drop
2.0 Volt/div

Load Current
2.0 Amp/div

Horizontal Scale
2mS/div

Figure 4 Voltage Drop Across B-1 Power Controller with 1.5 Ampere Load



Voltage Drop
2.0 Volt/div

Load Current
0.2 Amp/div

Horizontal Scale
2mS/div

Figure 5 Voltage Drop Across B-1 Power Controller with 0.15 Ampere Load

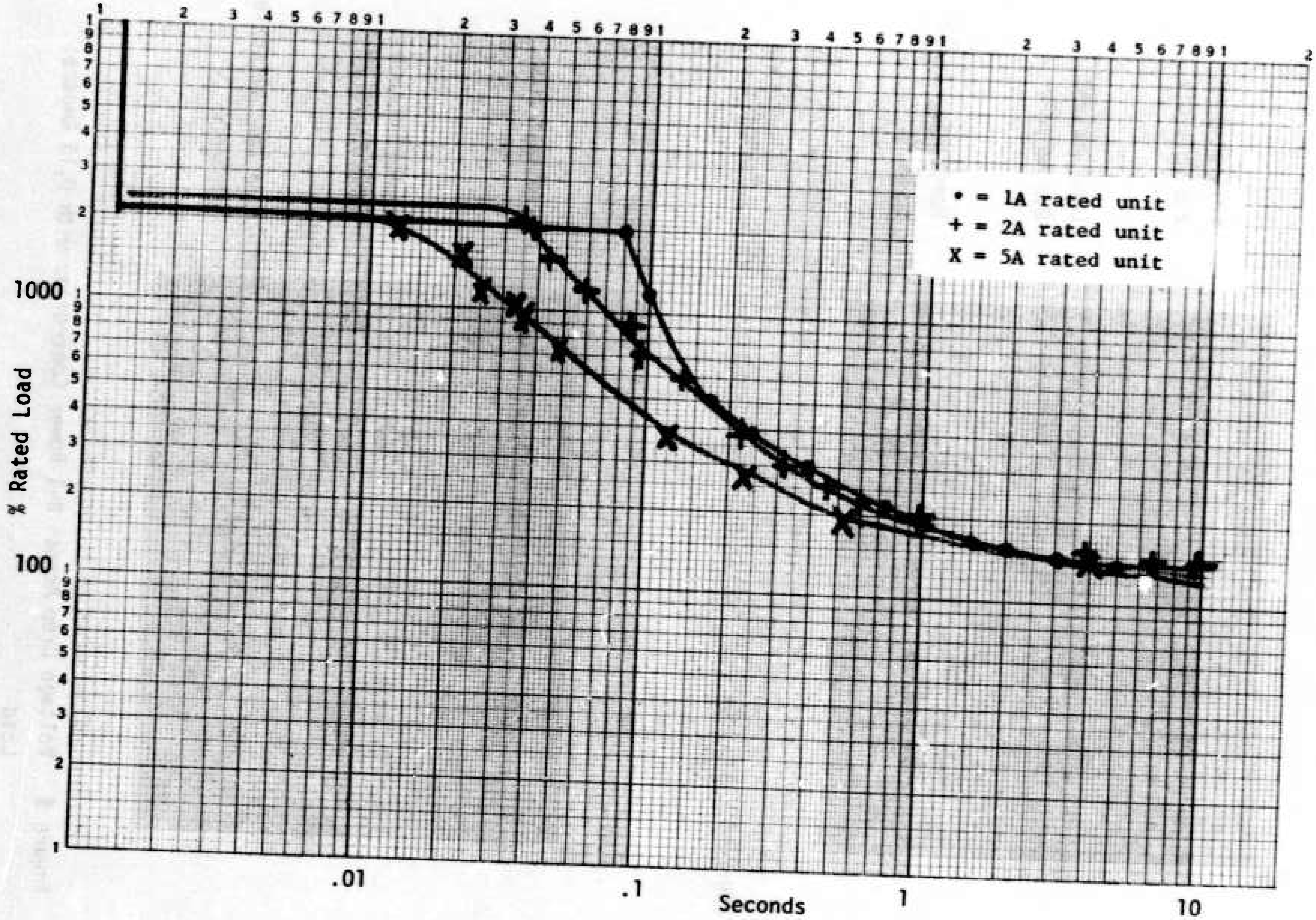


Figure 6. Trip Curve for Westinghouse Prototype Solid State Power Controllers

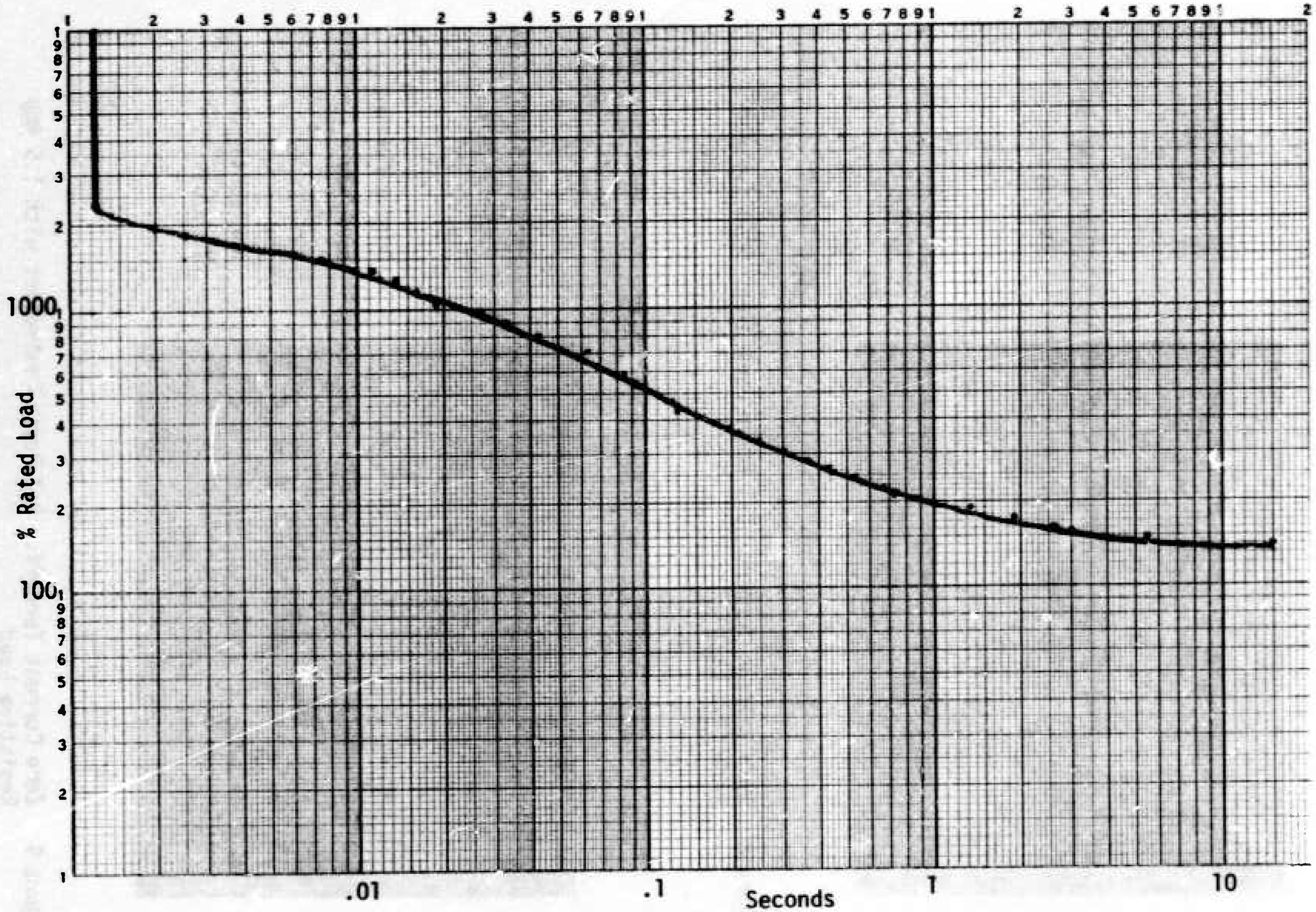
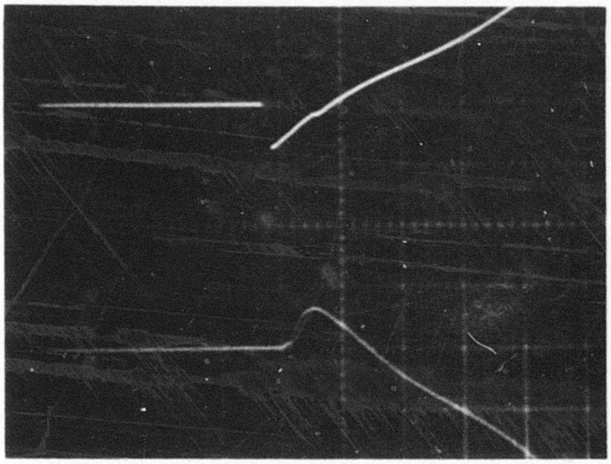


Figure 7. Trip Curve for B-1 Power Controllers

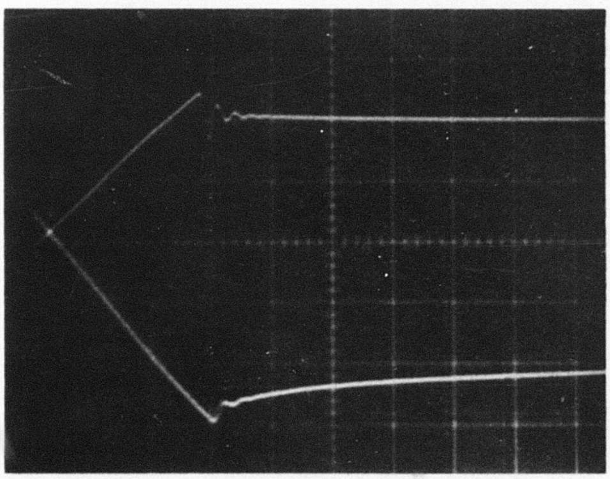


Output Voltage
10 Volts/div

Output Current
50mA/div

Horizontal Scale
10μS/div

Figure 8 Zero Voltage Turnon. B-1 Power Controller with 1.5 Amp Resistive Load

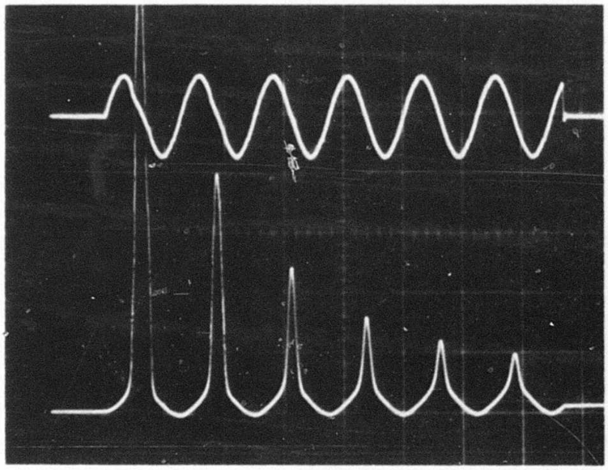


Output Voltage
10 Volts/div

Output Current
50mA/div

Horizontal Scale
10μS/div

Figure 9 Zero Current Turnoff. B-1 Power Controller with 1.5 Amp Resistive Load

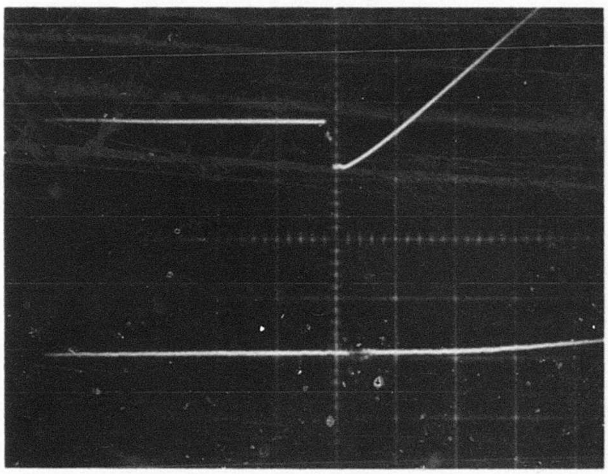


Output Voltage
500 Volts/div

Output Current
1 Amp/div

Horizontal Scale
2mS/div

Figure 10 Turnon and Turnoff of B-1 Power Controller with B-1 Transformer-Rectifier as Load

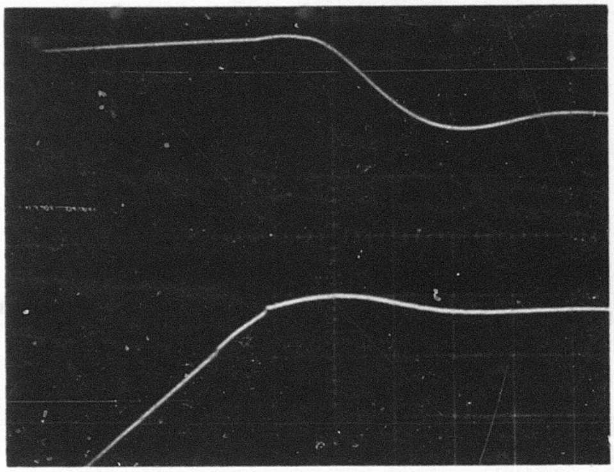


Output Vcltage
10 Volts/div

Output Current
10mA/div

Horizontal Scale
10μS/div

Figure 11 Magnified View of Figure 10 Showing Zero Voltage Turnon



Output Voltage
200 volts/div

⟵ zero

Output Current
10mA/div

⟵ zero

Horizontal Scale
10μS/div

Figure 12 Magnified View of Figure 10 Showing Zero Current Turnoff

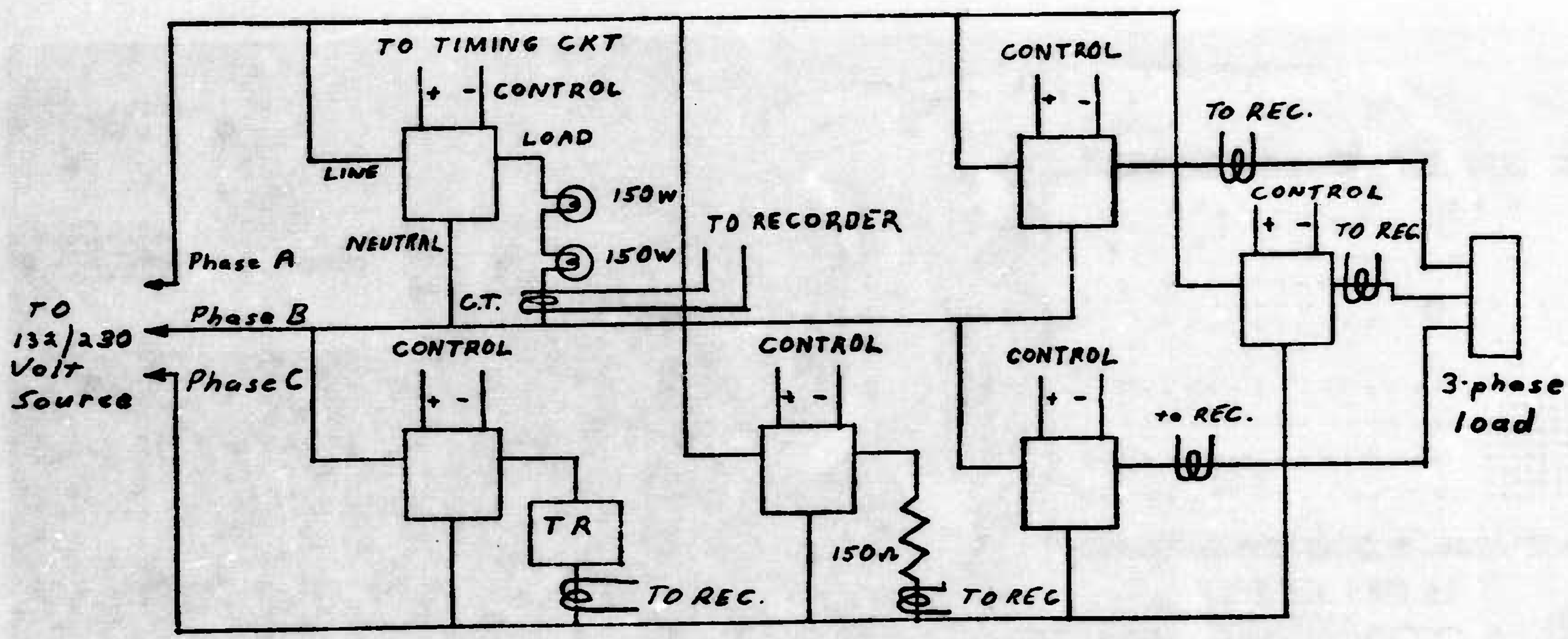


Figure 13 B-1 Power Controller Life Test Configuration

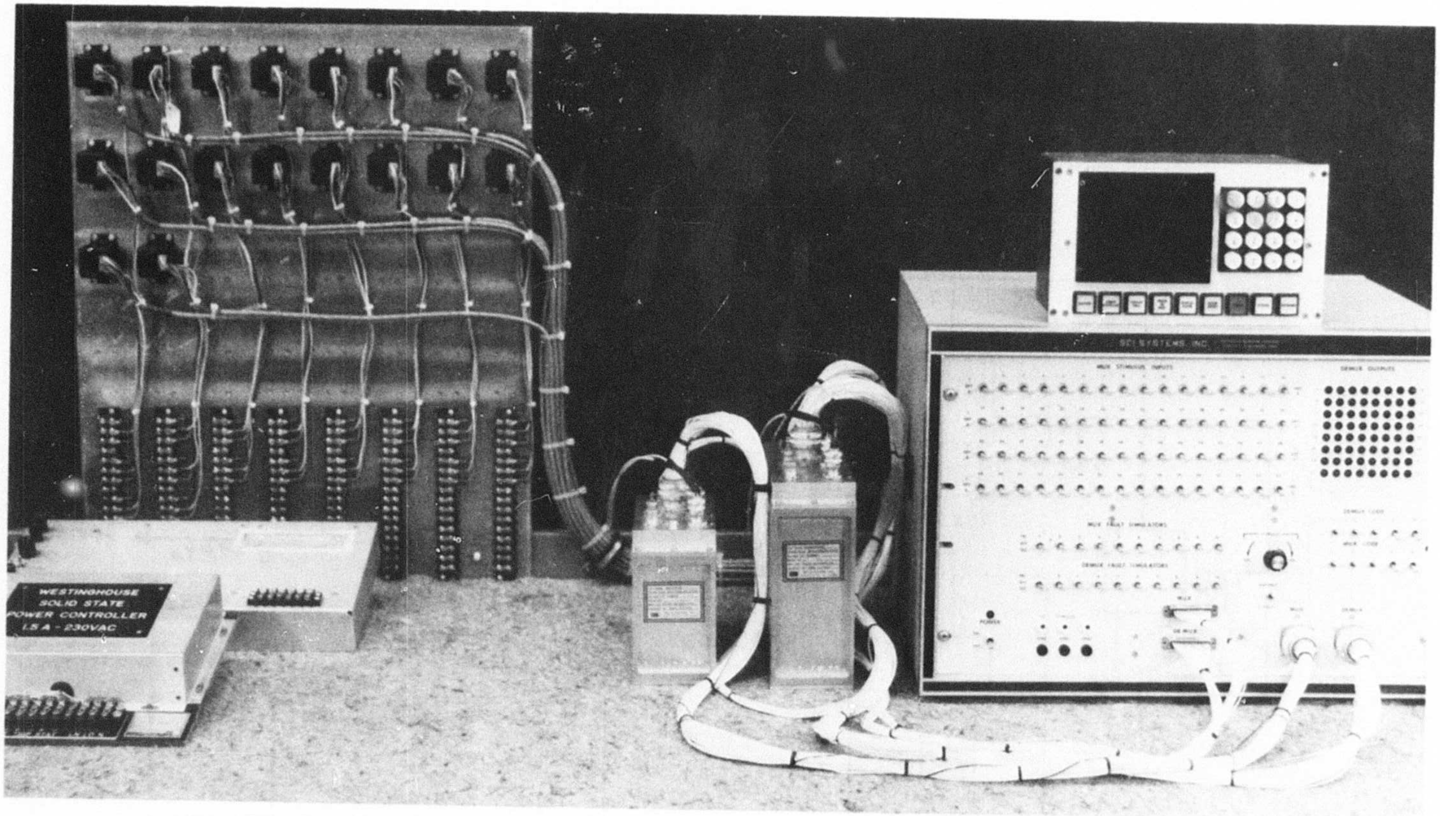


Figure 14   B-1 Power Controller and Laboratory EMUX Test Configuration

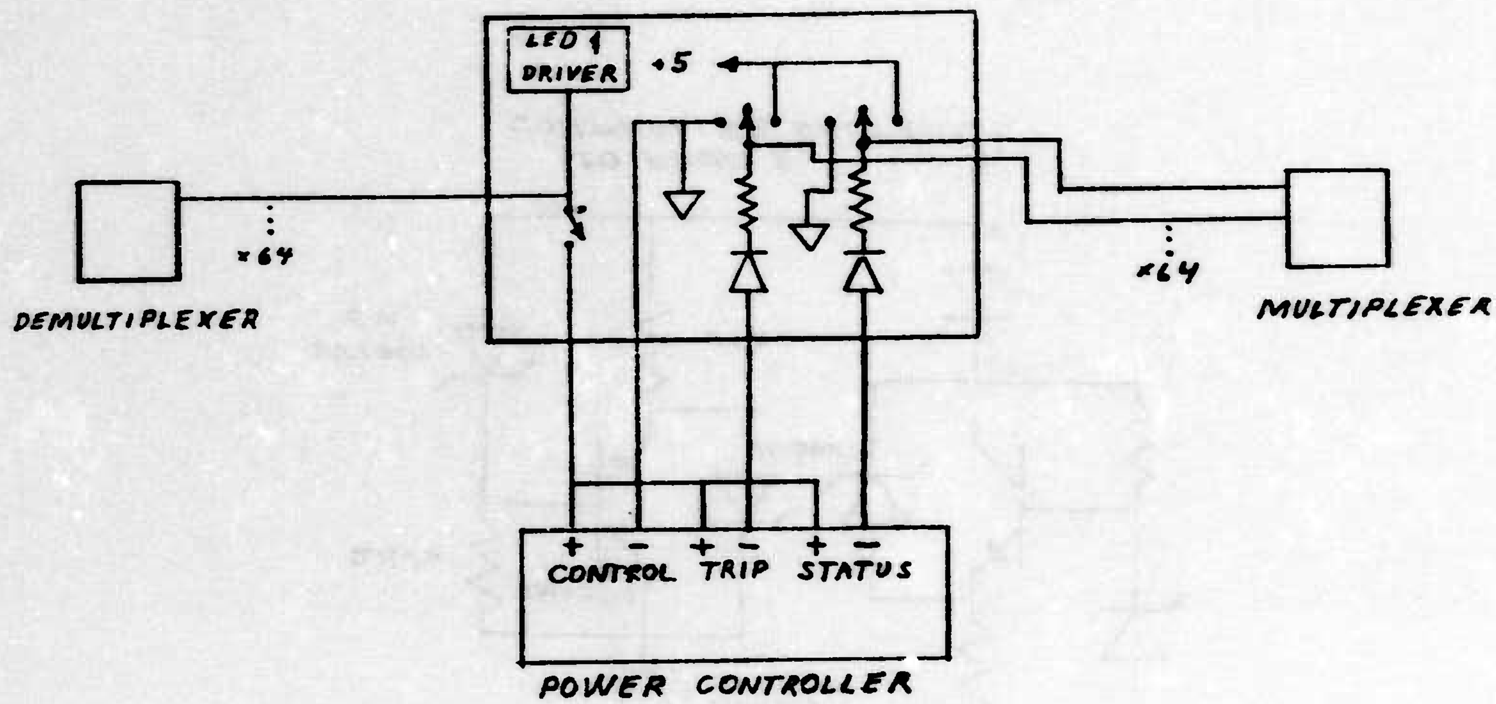


Figure 15 Power Controller/EMUX Wiring

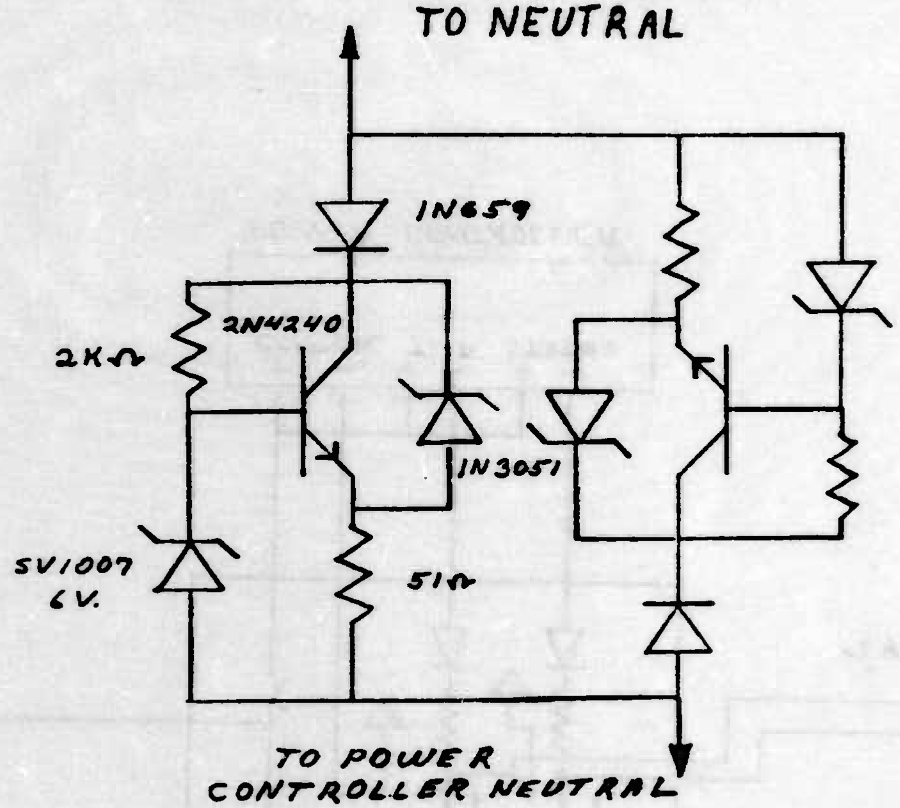


Figure 16 Current Limit Circuit for B-1 Power Controllers

Load	Power Controller Number
1) 3 Phase	1, 2, 9, 10, 17
2) 1.0 A resistive	3
3) 0.5 A resistive	11
4) 50 w lamp	5
5) 300 w lamp	13
6) 2.4 H inductive	12
7) 1/2 wave (B-1 relay)	4
8) Capacitive	6, 14
9) Light resistive	7, 15
10) Two power controllers in series to 0.5 A load	8, 16

Figure 17   List of Loads for Power Controller/EMUX Test

APPENDIX

POWERTRAN LISTING FOR DATA HANDLING SYSTEM

```
POWERTRAN    VER. 1  MOD. 0          TERM DEFINITIONS                      PAGE  1
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
/      ***** P C   T E S T      *****
/
/      THIS PROGRAM OPERATES WITH THE POWER CONTROLLER TEST HARDWARE
/      UP TO TWENTY POWER CONTROLLERS CAN BE MANUALLY SWITCHED
/      ON OR OFF, OR AUTOMATICALLY CYCLED AT SEVERAL RATES
/      TRIP INPUTS CAN BE SIMULATED BY SWITCHING THE RESPECTIVE
/      SWITCH TO ONE, THEN TO OFF, TO ONE AGAIN, ETC, EITHER 2 OR 3
/      TIMES.  DEPENDING ON THE COUNTER LIMIT   THE STATUS CAN BE
/      CHECKED VIA THE CCDP IN THE USUAL  MANNER       /
/
/UNITS/                                                                  000100
CCDP = D32                                                               000110
MTR = M07                                                                000120
OTR = D07                                                                000130
/
/           DUMMY VARIABLES          /
/
PCT = DUMMY /  POWER CONTROLLER TRIPPED
CON = DUMMY / CONTROL OUTPUT                                             000150
OVL = DUMMY  /OVERLOAD TRIP INPUT                                        000160
STS = DUMMY  /STATUS INPUT                                               000170
FLC = DUMMY  /FLASH-AUTO CYCLE                                           000180
AAA = DUMMY  /TRIP SUBTERM - DELAY                                       000190
AAC = DUMMY  /TRIP SUBTERM - INPUT TO TRIP COUNTER                       000200
ACC = DUMMY  /TRIP SUBTERM - OUTPUT FROM TRIP COUNTER                    000210
AEC = DUMMY  /TRIP COUNTER RESET -ON ZERO OF SWITCH                      000220
RES = DUMMY  /RESISTOR LOAD TERM + TRIP
COL = DUMMY  /INDUCTIVE LOAD TERM + TRIP                                 000250
LMP = DUMMY  /LAMP LOAD TERM + TRIP                                      000260
SER = DUMMY  /2 PC'S IN SERIES + TRIP                                    000270
CAP = DUMMY  /CAPACITOR LOAD TERM + TRIP                                 000280
LTE = DUMMY  /LIGHT RESISTIVE LOAD TERM + TRIP                           000290
NLD = DUMMY  /NO LOAD TERM + TRIP                                        000300
FWR01 = DUMMY  /MOTOR FORWARD                                            000310
REV01 = DUMMY  /MOTOR REVERSE                                            000320
MOT01 = DUMMY  /MOTOR TRIPPED                                            000330
/
/COUNTERS/                                                               000340
/
C(WAA00,1,3)  = AAC01(1),ACC01(1),AEC01(0)
C(WAC00,1,3)  =AAC06(1),ADC06(1),AEC06(0)
C(WAE00,1,3)  = AAC07(1),ACC07(1),AEC07(0)
C(WAF00,1,3)  = AAC08(1),ACC08(1),AEC08(0)
C(WAG00,1,2)  = AAC09(1),ACC09(1),AEC09(0)
C(WAH00,1,3)  = AAC10(1),ACC10(1),AEC10(0)
C(WAL00,1,3)  = AAC11(1),ACC11(1),AEC11(0)
C(WAM00,1,2)  = AAC12(1),ACC12(1),AEC12(0)
C(WAN00,1,2)  = AAC13(1),ACC13(1),AEC13(0)
C(WAO00,1,2)  = AAC14(1),ACC14(1),AEC14(0)
C(WAP00,1,2)  = AAC15(1),ACC15(1),AEC15(0)
```

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
C(WAR00,1,2) = AAC16(1),ACC16(1),AEC16(0)
C(WAS00,1,2) = AAC17(1),ACC17(1),AEC17(0)
C(WAT00,1,2) = AAC18(1),ACC18(1),AEC18(0)
/
/         STATUS  INPUTS
/
STS01 = MTR01                                                           000500
STS02 = MTR02                                                           000510
STS03 = MTR03                                                           000520
STS04 = MTR04                                                           000530
STS05 = MTR05                                                           000540
STS06 = MTR06                                                           000550
STS07 = MTR07                                                           000560
STS08 = MTR08                                                           000570
STS09 = MTR17                                                           000650
STS10 = MTR18                                                           000670
STS11 = MTR19                                                           000680
STS12 = MTR20                                                           000690
STS13 = MTR21                                                           000700
STS14 = MTR22                                                           000710
STS15 = MTR23                                                           000720
STS16 = MTR24                                                           000730
STS17 = MTR33                                                           000820
STS18 = MTR34                                                           000830
/
/         TRIP  INPUTS
/
OVL01 = MTR09                                                           000580
OVL02 = MTR10                                                           000590
OVL03 = MTR11                                                           000500
OVL04 = MTR12                                                           000610
OVL05 = MTR13                                                           000620
OVL06 = MTR14                                                           000630
OVL07 = MTR15                                                           000640
OVL08 = MTR16                                                           000650
OVL09 = MTR25                                                           000740
OVL10 = MTR26                                                           000750
OVL11 = MTR27                                                           000750
OVL12 = MTR28                                                           000770
OVL13 = MTR29                                                           000780
OVL14 = MTR30                                                           000790
OVL15 = MTR31                                                           000800
OVL16 = MTR32                                                           000810
OVL17 = MTR41                                                           000840
OVL18 = MTR42                                                           000850
OVL19=MTR43
OVL20=MTR44
/
/              SWITCH  INPUTS
/
```

```
                  1         2         3         4         5         6         7         8
         12345678901234567890123456789012345678901234567890123456789012345678901234567890
P(S1 ) = MTR45             / MOTOR ON    /
P(S2 ) = MTR46       /     MOTOR FORWARD ON, REVERSE OFF   /
P(S3 ) = MTR47             /  SERIES POWER CONTROLLERS ON   /
P(S4 ) = MTR48             /     NOT USED ///
P(S5 ) = MTR49             / TEST CONTROLLER NUMBER 20   /
P(S6 ) = MTR50             / RESISTOR LOAD NUMBER ONE   /
P(S7 ) = MTR51              /  RESISTOR LOAD NUMBER TWO  /
P(S8 ) = MTR52             /  RELAY LOAD, HALF WAVE    /
P(S9 ) = MTR53             / INDUCTOR LOAD  /
P(S10) = MTR54             /  50 WATT LIGHT BULB   /
P(S11) = MTR55             /  TWO 150 WATT LIGHT BULBS   /
P(S12) = MTR56             / NUMBER ONE OF TWO IN SERIES   /
P(S13) = MTR57             /  NUMBER TWO OF TWO IN SERIES   /
P(S14) = MTR58             /  CAPACITIVE LOAD NUMBER ONE   /
P(S15) = MTR59             /  CAPACITIVE LOAD NUMBER TWO  /
P(S16) = MTR60             /  LIGHTLY LOADED POWER CONTROLLER NUMBER ONE ///
P(S17) = MTR61             /  LIGHTLY LOADED POWER CONTROLLER NUMBER TWO  /
P(S18) = MTR62             /  NO LOAD ON POWER CONTROLLER  /
P(S33) = MTR63             /  AUTO CYCLE ONE  /
/
```

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

THE FOLLOWING MUX/DEMUX TERMINAL ADDRESSES HAVE NOT BEEN ASSIGNED
MUX   DEMUX
 1      1
 2      2
 3      3
 4      4
 5      5
 6      6
 8      8
 9      9
10     10
11     11
12     12
13     13
14     14
15     15
16     16
17     17
18     18
19     19
20     20
21     21
22     22
23     23
24     24
25     25
26     26
27     27
28     28
29     29
30     30
31     31
```

```
POWERTRAN   VER. 1  MOD. 0          EQUATIONS
                                 3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
/       OUTPUT TO POWER CONTROLLERS    /
/
OTR01=CON01                                                             001080
OTR02 = CON02                                                           001090
OTR03 = CON03                                                           001100
OTR04 = CON04                                                           001110
OTR05 = CON05                                                           001120
OTR06 = CON06                                                           001130
OTR07 = CON07                                                           001140
OTR08 = CON08                                                           001150
OTR09 = CON09                                                           001160
OTR10 = CON10                                                           001170
OTR11 = CON11                                                           001180
OTR12 = CON12                                                           001190
OTR13 = CON13                                                           001200
OTR14 = CON14                                                           001210
OTR15 = CON15                                                           001220
OTR16 = CON16                                                           001230
OTR17 = CON17                                                           001240
OTR18 = CON18                                                           001250
OTR19=CON19
OTR20=CON20
/
/         EXTRA OUTPUTS      /
/
OTR21=CON21*FLC07
OTR22=CON22 *-FLC07
OTR23=CON23 +FLC07
OTR24=CON24 +-FLC07
/
/       DISPLAYS  A  WHEN AUTO CYCLE ONE IS ON    /
/        DISPLAYS  M  WHEN AUTO CYCLE NUMBER ONE OFF   /
/
OTR25 = ZERO
OTR26 = -S33                                                            001260
OTR27 = ZERO
OTR28 = S33                                                             001270
OTR29 = S33                                                             001280
OTR30 = ZERO
OTR31 = -S33                                                            001290
OTR32 = ZERO
OTR33 = ZERO
OTR34 = -S33                                                            001300
OTR35 = ONE                                                             001310
OTR36 = ZERO
OTR37 = ZERO
OTR38 = ONE                                                             001320
OTR39 = -S33                                                            001330
OTR40 = ZERO
OTR41 = ZERO
```

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
OTR42 = ONE                                                             001340
OTR43 = S33                                                             001350
OTR44 = ONE                                                             001360
OTR45 = ONE                                                             001370
OTR46 = S33                                                             001380
OTR47 = ONE                                                             001390
OTR48 = ZERO
OTR49 = ZERO
OTR50 = ONE                                                             001400
OTR51 = ZERO
OTR52 = ZERO
OTR53 = ZERO
OTR54 = ZERO
OTR55 = ONE                                                             001410
OTR56 = ZERO
OTR57 = ZERO
OTR58 = ONE                                                             001420
OTR59 = ZERO
OTR50 = ZERO
OTR51 = ZERO
OTR52 = ZERO
OTR53 = ONE                                                             001430
/
/
/AUTO RUN/                                                              001440
/
T1(10),T0(10),FLC04=-FLC04*MTR35  /  SWITCH 35, 5 HZ CYCLE RATE  /
T1(33),T0(33),FLC05=-FLC05*MTR36  /  SWITCH 36, 1,52 HZ CYCLE RATE  /
T1(100),T0(100),FLC06=-FLC06*MTR37/  SWITCH 37, 0,5 HZ CYCLE RATE  /
FLC07=FLC04+FLC05+FLC06               /  FLASH RATE 2 OUTPUT  /
T1(3000),T0(3000),FLC03 = -FLC03*S33   /  SWITCH 63, 30 SEC FWD, 30 SEC REV /
T1(10),T0(10),FLC02=-FLC02*S33         /  SWITCH 63, 5 HZ CYCLE RATE  /
T1(50),T0(50),FLC01 = -FLC01*S33       /  SWITCH 63, 1 HZ CYCLE RATE  /
/
/ 3 PHASE REVERSING /                                                   001670
/
/  FORWARD + NO TRIP + NO TRIP LIMIT     /
/
CON01=CON09=CON27=FWR01*-AAA01*-ACC01
/
/     REVERSE + NO TRIP + NO TRIP LIMIT        /
/
CON37=CON10=CON02=REV01*-AAA01*-ACC01
CON17=CON27+CON37
/
/     FORWARD   ON AFTER TWO SECOND DELAY    /
/
T1(200),FWR01 = -S33*S1*S2+FLC03*S33                                    001700
/
/     REVERSE   AFTER TWO SECOND DELAY   /
```

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
/
T1(200),REV01 = -S33*S1*-S2*-FLC03*S33                                    001710
/
/     OFF   ON ANY TRIP    /
T1(25),T0(25),AAA01=OVL01+OVL02+OVL09+OVL10+OVL17                         001720
/
/     IN PUT TO COUNTER     /
/
AAC01 = AAA01                                                             001730
/
/     RESET COUNTER ON ZERO OF CONTROL SWITCH     /         /
/
AEC01 = S1                                                                001740
/
N(2),MOT01 = ACC01  /NOTIFY TRIP
/
/
/  RESISTIVE LOAD  /                                                      001760
/
CON03=RES11*-AAA06*-ACC05
CON11=RES12*-AAA07*-ACC07
RES11=S6   +FLC07                                                         001790
RES12=S7+FLS02                                                            001800
T1(25),T0(25),AAA06=OVL03                                                 001810
AAC06= AAA06                                                              001820
AEC06=S6                                                                  001830
N(2),RES01=ACC06
T1(25),T0(25) AAA07=OVL11                                                 001850
AAC07=AAA07                                                               001860
AEC07=S7                                                                  001870
N(2),RES02=ACC07
/
/  INDUCTIVE LOAD  /                                                      001890
/
CON04=COL11*-AAA08*-ACC08
CON12=COL12*-AAA09*-ACC09
COL11=S8   +FLC07                                                         001920
COL12=S9+FLS01                                                            001930
T1(100),T0(100),AAA08=OVL04                                               001940
AAC08=AAA08                                                               001950
AEC08=S8                                                                  001960
T1(25),T0(25),AAA09=OVL12                                                 001970
AAC09=AAA09                                                               001980
AEC09=S9                                                                  001990
N(2),COL01=ACC08
N(2),COL02=ACC09
/
/  LAMP LOAD  /                                                           002020
/
CON05=LMP11*-AAA10*-ACC10
```

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
CON13=LMP12*-AAA11*-ACC11
LMP11=S10 +FLC07                                                          002050
LMP12=S11+F.C01                                                           002060
T1(100),T0(100),AAA10=OVL05                                               002070
T1(25),T0(25),AAA11=OVL13                                                 002080
AAC10=AAA10                                                               002090
AAC11=AAA11                                                               002100
AEC10=S10                                                                 002110
AEC11=S11                                                                 002120
N(2),LMP01=ACC10
N(2),LMP02=ACC11
/
/ TWO IN SERIES  /                                                        002150
/
CON08=SER11*-AAA12*-ACC12
CON16=SER12*-AAA13*-ACC13
SER11=S12+S3   +FLC07                                                     002180
SER12=S13+S3   +FLC07                                                     002190
T1(25),T0(25),AAA12=OVL08                                                 002200
T1(25),T0(25),AAA13=OVL13                                                 002210
AAC12=AAA12                                                               002220
AAC13=AAA13                                                               002230
AEC12=S12                                                                 002240
AEC13=S13                                                                 002250
N(2),SER01=ACC12
N(2),SER02=ACC13
/
/  CAPACITIVE LOAD  /                                                     002280
/
CON06=CAP11*-AAA14*-ACC14
CON14=CAP12*-AAA15*-ACC15
CAP11=S14     +FLC07                                                      002310
CAP12=S15+FLC01                                                           002320
T1(50),T0(52),AAA14=OVL05                                                 002330
T1(25),T0(25),AAA15=OVL14                                                 002340
AAC14=AAA14                                                               002350
AAC15=AAA15                                                               002360
AEC14=S14                                                                 002370
AEC15=S15                                                                 002380
N(2),CAP01=ACC14
N(2),CAP02=ACC15
/
/  LIGHT LOAD  /                                                          002410
/
CON07=LTE11*-AAA16*-ACC16
CON15=LTE12*-AAA17*-ACC17
LTE11=S16   +FLC07                                                        002440
LTE12=S17+F.C01                                                           002450
T1(50),T0(50),AAA16=OVL07                                                 002460
T1(25),T0(25),AAA17=OVL15                                                 002470
```

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

AAC16=AAA16                                                               002480
AAC17=AAA17                                                               002490
AEC16=S16                                                                 002500
AEC17=S17                                                                 002510
N(2),LTE01=ACC16
N(2),LTE02=ACC17
/
/  NO LOAD  /                                                             002540
/
CON18=NLC01*-AAA18*-ACC18
NLC01=S18*-FLC02                                                          002560
TI(50),TC(50),AAA18=OVL18                                                 002570
AAC18=AAA18                                                               002580
AEC18=S18                                                                 002590
N(2),NLC01=ACC18
/       POWER CONTROLLER CONNECTED TO POWER, 230 VOLTS,
/  EMUX OUTPUT TO STATUS AND TRIP SWITCHES     TO SEE IF ANY ONE SWITCH CLOSES  E
/     EVEN THOUGH POWER CONTROLLER IS OFFFF/
/
CON19 = ONE
N(2),NLC19 = OVL19
/
/                    TEST POWER CONTROLLER
/
CON20 = S4+FLC07
/
/                    NOTIFY WHEN TRIP = 1
/
N(2),PCT01 = OVL20
/
/
/
/
/
```

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
```

SYSTEM INTERNAL TABLE STATUS

COMMENT	% FULL	TABLE NAME
	13	SYMBOL TABLE

GENERATED TABLE STATUS

COMMENT	% FULL	TABLE NAME
	40	SCRATCHPAD TEMPORARY STORAGE
	11	PROTECTED IOC
	10	UNPROTECTED IOC
	6	PROTECTED EQUATION PARAMETER
	17	UNPROTECTED EQUATION PARAMETER
	7	DATA BIT STORAGE
	25	NOTIFICATION TABLE

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